BEYOND EINSTEIN: From the Big Bang to Black Holes

Science Requirements Document (SRD)- Overview

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What is an Science Requirements Document?

- Part of official NASA documents defining mission (Phase A)
- Describes science programs which SET REQUIREMENTS and GOALS on the mission (not *every* science project, ala ODRM)
- Includes TLRD (Top Level Requirements Document) requirements, but has more detail
  - 2000 TLRD assembled w/ FST oversight/input
  - 'final' version matches 2003 TRIP (Technical Readiness and Implementation Plan)
- SRD Describes How and Why each science program sets requirements/goals in each
- Is Instrument non-specific prior to Phase A instrument selection, may change after instrument selection.

Top Level Requirements Doc (TLRD)

- Final official version frozen at 'TRIP' version (circa 2003, dated 12/08/05)
- FST input to GOALS captured until Dec 2005
- Contains ~no science justification - No longer being worked – SRD takes precedence
- On Con-X Web site: constellation.gsfc.nasa.gov -> Project -> Mission Documents

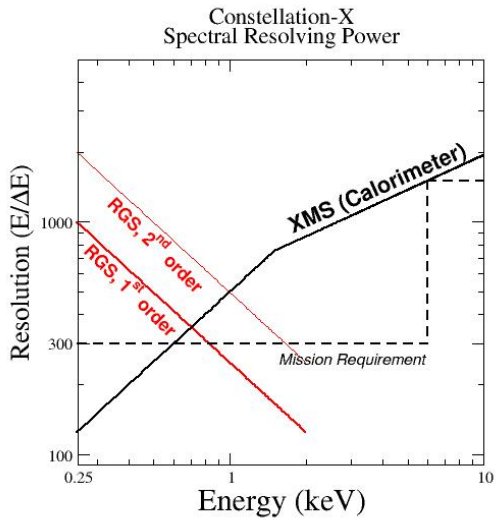
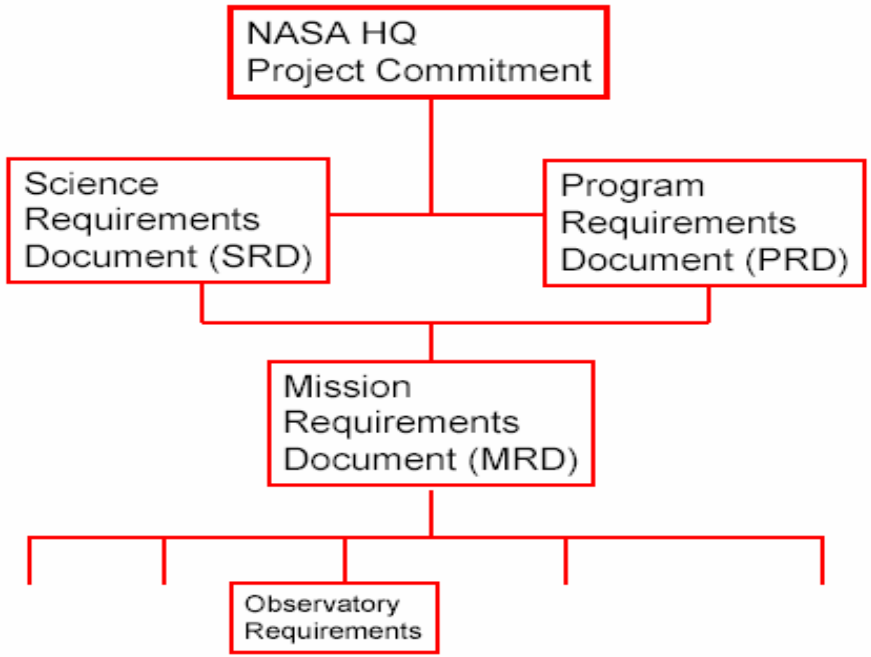


Table I
Minimum Resolving Power

Energy (keV)	Minimum Mission Spectral Resolving Power (E/ΔE)	Goals
0.25 — 6.0	300	3000
6.0 — 10.0	1500	3000
10 — 40	10	TBD

Relation to Other mission Docs

- Flow chart
- We are working to L2 – no instrument specificity



SRD Progress, Plans

- Since last FST meeting
- Worked out structure, key params, sensitivity not just a(e) as in TLRD 6 ‘derived’ parameters
    - •bandpass
    - •area/sensitivity
    - •Spectral Resolution
    - •PSF/HPD
    - •FOV
    - •Other (these ARE requirements!)

SRD Progress, Plans

- Since last FST meeting
- Draft 0 Aug 2005 (partial 6 params)
    - Input: DETF papers, May 05 science book, white papers, TRIP, Study Team Telecons, TLRD (no longer being worked)
- Fleshing out 6 params for ~15 science topics (may double?)
    - 5 done to date – Input from speakers here, WP, Booklet
    - Need FST input/review on all others - White Papers, Sub-teams?
- Full Draft end of summer at current rate, end of year if topics double

Example SRDs from other missions

- **GLAST – most useful model so far. ($500m)**
  - GLAST science requirements document (September 23, 2000 version (version AFTER the instrument AO and selection) 32 pages
  - July 1999 Version (released with the instrument AO, **not instrument specific**) 17 pages!
- **Swift – more recent than GLAST (Explorer class)**
  - Contained as appendix to 'Approval to Proceed', 8 pages short (Feb 01).
  - Updated 10 months later (Dec 01).
- **XEUS – 30 pages**
  - 5/11/2005 by Arvind Parmar – 10 performance params per topic (added Time Resolution, Max Count rate, Polarimetry, Obs constraints)
- **JWST – 114 Pages ($4B)** (SRD length correlation?)
  - Requirements collected separately from science topics

Sources – 'other applicable docs'

- primary source: 'Science with Constellation-X' booklet of May 2005, NASA/TP-2005-212784.
- FST white papers written during 2004 and 2005
- NSF/NASA Dark Energy Task Force (June 2005) White Paper (Allen etal)
- Con-X TRIP report (Feb 2003)
- Top Level Requirements Document
- 2000 NRC Decadal Survey 'Astronomy and Astrophysics in the New Millennium'.
- 'Connecting Quarks to the Cosmos' NRC report
- Original Proposals, "The Next Generation X-ray Observatory' PI N. White, Large Area X-ray Spectroscopy Mission', PI H. Tananbaum
- an interim report to NASA (May 1996) 'The High Throughput X-ray Spectroscopy (HTXS) Mission'

Definitions: Requirements, Minimum, Goal

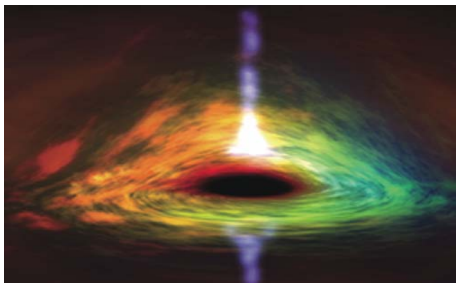
- Requirement: Design level. Failure to meet triggers a Project Change Control Review (internal to project. this is what the SRD aims at. IE: 1.5m^2 at 1.25keV)
- Minimum: Level below which, if violated, significantly compromises the scientific return of the mission. Failure to meet triggers a NASA Program Review (external to project. In TRIP IE: 1.2m^2 at 1.25keV, TBD for Phase A, SRD.)
- Goal: Level which, if met, produces significantly enhanced scientific return. (Also in SRD, IE: 5'' HPD)

Current Form

- Chapters follow TRIP and Science Booklet – 4 topics (TBR 3?)
  - Black holes
  - Dark energy/matter
  - Growth of cosmic structure and impact of black holes (aka feedback!)
  - Life cycles of matter
- 3 or 4 science investigations under each topic
- 6 Key Parameters under each investigation
  - Bandpass, Area/Sensitivity, Spectral Resolution, PSF/HPD, FOV, Other
  - populate for ALL sub-topics, even if no impact. IE: 10 brightest AGN, reverb mapping, several arcmin fine, next 1000 AGN, PSF ~arcmin fine.
- REARRANGEMENT very likely – but for now, concentrate on content
- Should be SPECIFIC, DETAILED (long) for now – capture content, can compress later if needed. Currently at 40 pages (1/2 done? Growth?).

Organization of the Science Requirements Document

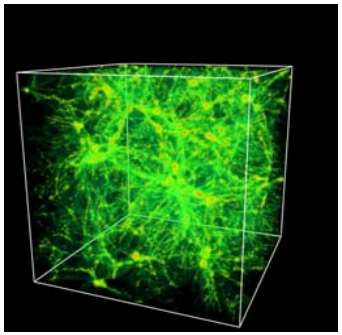
3-4 chapters organized around the science goals of the mission:



Black Holes

Observe hot matter spiraling into **Black Holes** to test the effects of General Relativity

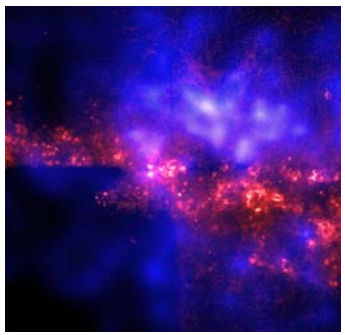
Trace their **evolution with cosmic time**, their contribution to the energy output of the Universe and their effect on galaxy formation



Dark Matter and Dark Energy

Use clusters of galaxies to trace the locations of **Dark Matter** and as independent probes to constrain the amount and evolution of **Dark Energy**

Search for the **missing baryonic matter** in the Cosmic Web



Cycles of Matter and Energy

Study dynamics of **Cosmic Feedback**

Creation of the elements in **supernovae**, The equation of state of **neutron stars, Stellar activity, proto-planetary systems** and X-rays from **solar system objects**

TOC

Split?

TOC

Add S-Z

TOC

LOTs to Do here..

And here…

Observational Description										Derived Performance Requirements					
Science Objective	Science Investigation	Target Catagory	Type of Observation	# targets	# obs per target	Source extent	Flux (min, max) 0.25-10	S/N	Typical Exposure Time per obs	Band-pass	Area m^2 @keV	Spectral R – FWHM @keV	Angular R - HPD	Instantaneous FOV	Other
Strong Gravity and Black Holes 1.0	Study GR 1.1	Bright AGN 1.1.1	Spectra, Timing = Reverb	30	5-10	point	10^{-11}	>20 in Fe-K in 1ks	30ks	**0.5-40.0**	**0.6 @6keV**	**1500 @6keV**	n/a	>5xPSF	
	BH Properties (Spin, Mass) 1.2	AGN 1.2.1	Spectra	50	2	point	10^{-14} 10^{-12}	>20 in Fe-K in 100ks	50ks	**0.5-40.0**	**1.5@1.25** 0.6@6 **0.15@40**	**1500 @6keV** **10@40**	**15''**	>5xPSF	
		IMBH 1.2.2	Spectra, timing	25	2	point	10^{-13} 10^{-12}	1000 in Fe-K in 10ks	30ks	0.5-10.0	0.6 @6keV	1500 @6keV	15''	>10xPSF	<400υs Timing for BHXN
Constrain the Nature of DE and DM and the missing Visible matter in the universe 2.0	DE EOS, DM, Cluster cores….														
	WHIM 2.4	100 Bgnd AGN	spectra	100	1	point	10^{-13} 10^{-11} (10^{-9} flare)	>10 in OVII	100ks	**0.25-1.0**	**0.1@0.25** *(goal 0.2 @0.5)*	*600-1200 (g3000) @0.5*	n/a	>5xPSF	TOOs possible

Plans: Process

- SRD team – Mike, Ann, Divas, Jay, Rob, Jean, IS + Science Management Team (SMT) …
- Recent comments from FST speakers
  - Steve Allen – 15'' may not be sufficient to do good job on f(gas)
    - need good **simulations** to really know
    - split DE into 3 sub-sections: f(gas), G(z), S-Z
  - Giorgio Matt – low Z AGN, metric from orbiting hot spots
  - Jon Miller – IMBH – 'spot on'
- Input from FST at FST meetings, split out sub-committees
  - Should follow 6 params form.

Plans: Vetting

- May not need official Project SRD until Phase A…. need a good draft sooner (NRA, instrument AO…)
- PS and PM need to sign off on SRD at Phase A
- NOW, need FST comments/input/simulations, need to present drafts to FST
- The SRD will be source or part of Level 1 and Level 2 official NASA documents

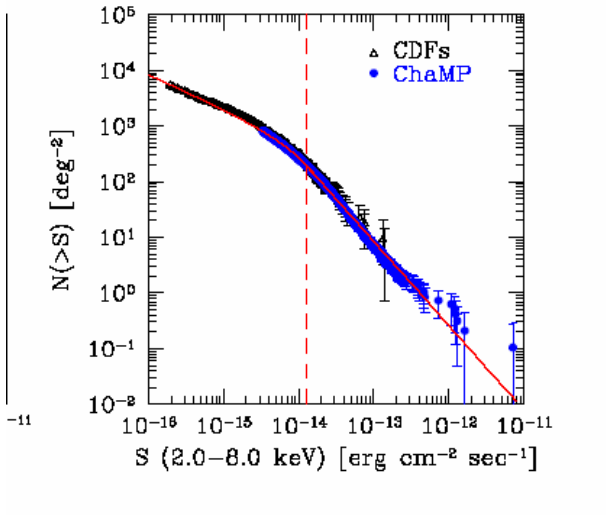
Plans: Questions

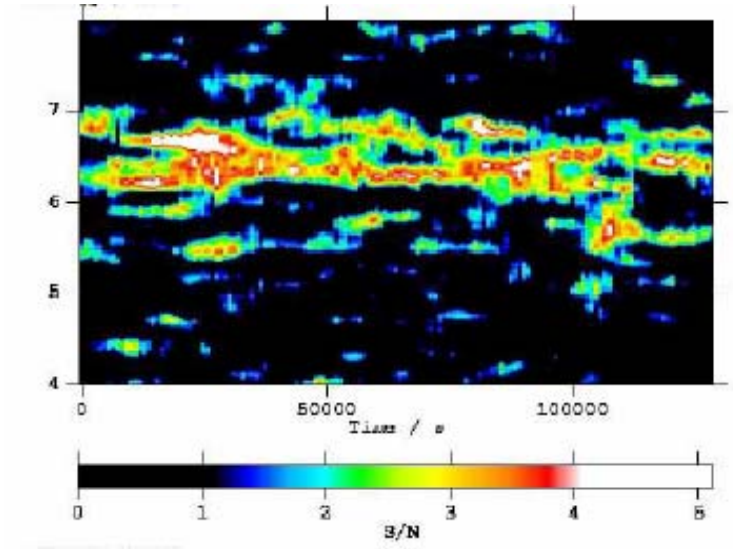
- Split out more science topics (15 becomes 30?)
- FST Teams to review and/or draft sections?
- Need a real simulation tool, perhaps some template PSFs, with HPD and 90% ECF. Gaussian, XMM like, best guess based on current reflectors?

1.2.1 – BH Properties, Spin, Mass

- Really 2 topics in one – should be split?
- Next factor of 10 down in flux, to few 10^{-12}, 'orbital timescale'
  - yields mass
  - Few thousand AGN at this flux level, all targeted observations
- Then, 10^{-12} -> 10^{-14}, where 'calibrated' Fe lines can be measured for spin
  - May include many serendipitous objects
  - Range of z

Orbital Timescales – few 10^{-12}

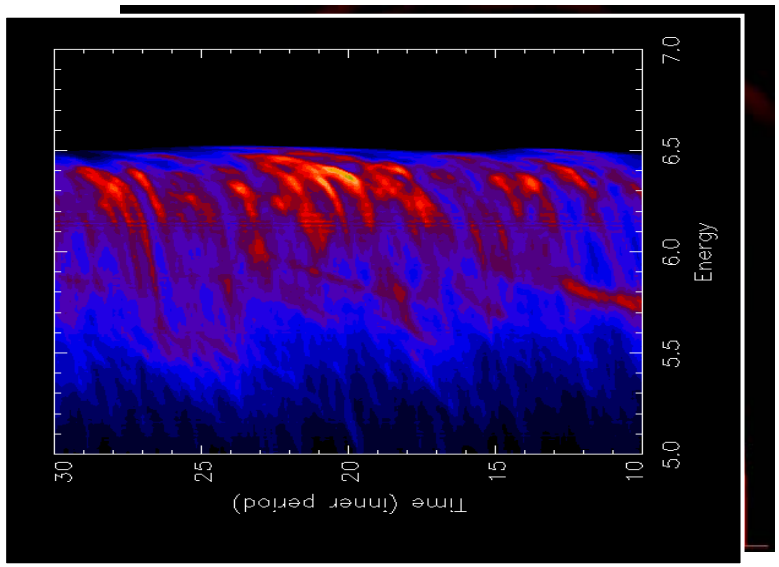




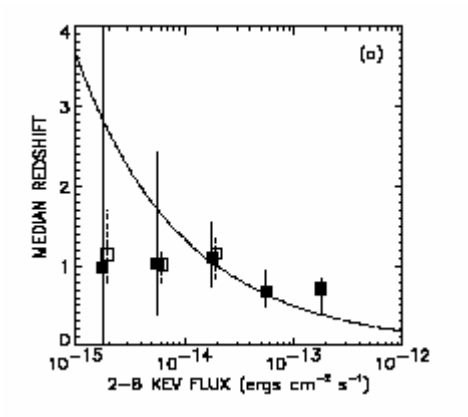
Data: Turner etal MKN 766 (XMM)

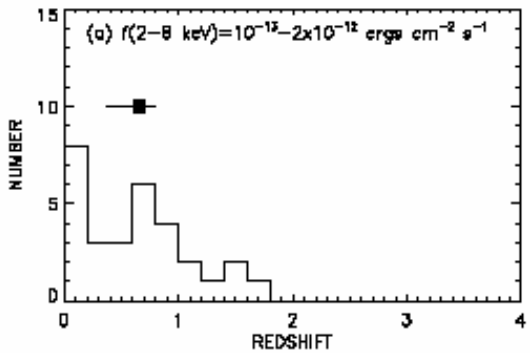
Numbers: Kim etal, ChaMP

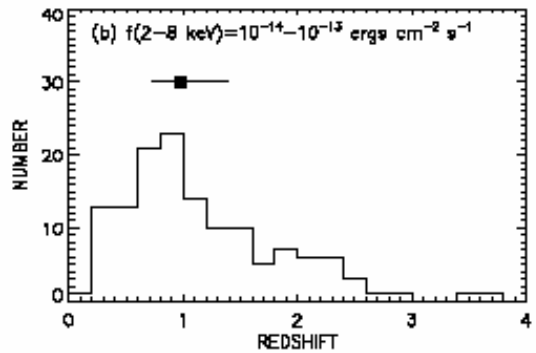
Simulation: Reynolds ---------->

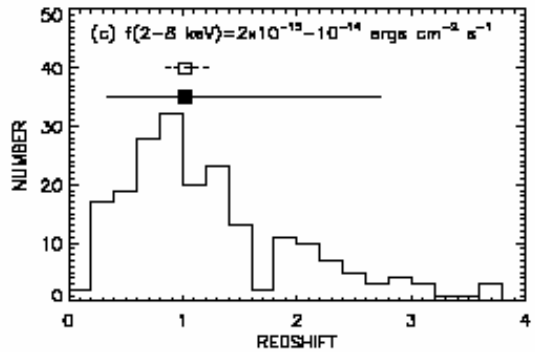


Accurate Fe lines, but not time resolved (10^{-12} – 10^{-14})









1.2.1 BH Properties from AGN

- STATEMENT of SCIENCE GOAL: Measure MASS, SPIN, and SPIN vs. z…..
- HOW? (1) While reverberation mapping studies will be possible only for the brightest AGN, studies of the flow of individual hot spots approaching the black hole will be possible for AGN approximately a factor of 10 fainter, (ie, down to 10^{-12} (2-10 keV) due to the fact that the orbital timescale at several gravitational radii is ~10x longer than the lightcrossing time scale…… These studies will allow us to map the structure of space-time near the black hole, determine spin, etc., and by building up time-averaged Fe line profiles will allow us to calibrate the time averaged Fe line profiles.
- HOW? (2): With the 'calibrated' time averaged profiles in hand, one can measure the spin properties and therefore space-time structure in large numbers of AGN via model fitting to their time averaged Fe line profiles, and determine the run of BH properties with cosmological time….

1.2.1.1 Bandpass

- **The full bandpass of 0.25-40 keV will be critical in studying inner accretion disks in AGN.** Although the primary feature has a rest-frame energy of 6.4-6.7 keV (Fe K), it will be gravitationally and/or cosmologically redshifted ($0 < z < 4$) in many cases, meaning that soft response down to 1-2keV will be required to characterize the line, and to softer energies to constrain both the continuum and the absorption in these complicated systems. We also note that Con-X will need a high energy capability in order to determine the magnitude of the Compton reflection bump (peaks at ~30keV) due to cold matter in the disk, and the high energy cutoff of the continuum (the spectral break predicted in the range 50-200 keV is redshifted into the 10-40 keV Con-X band for z~1-2). This high energy cutoff probes the physics of the flow in the accretion disk corona, yielding maximum electron temperatures and the degree of coupling between electrons and protons in 2-temperature flows.

1.2.1.2 Sensitivity/Area

- **An effective collecting area of 6000 cm^2 at 6 keV is required to carry out the studies of individual hot spots orbiting near the last stable orbit.**
  - in this particular science area, instantaneous effective area is of critical importance.
  - The orbital timescale is approximately 2500 seconds (for the last stable orbit).
- A 3-sigma detection of a 100eV equivalent width FeK line at 6keV, for a 2-10 keV AGN flux of 5 x 10^{-12} erg/cm^2/s, requires 2500 seconds with an effective area of 6000cm^2 at FeK.
  - Exposures of 100,000sec will allow ..calibration of the time averaged profiles which will be obtained at lower flux levels.
- Investigation of the evolution of BH parameters (ie, spin) with cosmic time
  - will require 6000cm^2 at ~6keV around the peak of the AGN age (ie, z~1.5)
  - and also 15,000 cm^2 at 1.25 keV for the higher z objects (1<z<3)
  - Long, 100ks exposures in targeted areas (the Lockman Hole, the CDF, etc) will collect 50,000 counts [10^{-14} 2-10 keV, a=1.7,nh=10^{18}, same at Nh=10^{20}], which is sufficient to accurately measure the shape of the FeK line.

1.2.1.3 Spectral Resolution

- **A spectral resolution of R=1500 at FeK is required for the brightest of these AGN (at fluxes of few 10^{-12}).**
  - crucial diagnostic: temperature -> ionization state of the iron line.
  - Kα-1 Δe=13eV, but Kα-2 at X+1, Δe~4eV, for different X=ionization states. EG, FeI Kα-2 has energy 6405 eV whereas FeII Kα-1 has energy 6408 eV. Kα-2 half the strength of Kα-1
  - Therefore need Δe=4eV, R=1500 @ 6keV
  - **For the higher z objects, we require R>500 at ~2keV.** This is because Fe K will be redshifted and the spacing between the lines similarly compressed. At z=2.5, FeK~ 2keV, and the average spacing is ~4eV between Kα-1.

1.2.1.4 Angular Resolution

- **Angular resolution is not a significant consideration for this science.** An ~arcmin beam would be sufficient to avoid the confusion limit in the faintest of these bright AGN (~10^{-14} erg/cm^2/s(2-10), 1/18 AGN per sq arc-min, Hasinger 2001, or 30% chance of an AGN in our baseline 2.5'x2.5' FOV). However background subtraction would be difficult with a beam this large and the baseline 2.5 arcmin FOV.

1.2.1.5 Instantaneous FOV

- **The FOV must be sufficient to allow accurate subtraction of the background from the source using the same image**, which should not be a large driver for the mission. From general statistical considerations, this requires a FOV at least 3 (TBR) times larger than the 90% (TBR) encircled energy function (ECF). The baseline FOV of 2.5' should be sufficient for the baseline PSF of 15'' HDP, unless the PSF has unusually strong wings.

1.2.1.6 Other

- We require that the instrument being used to make these observations operate with a high enough duty cycle that the required effective area is not impacted (<10%) by any instrumental **dead-time**. A **time resolution** of at least a few seconds is required for reverberation mapping.